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ON THE POSSIBILITY OF DETECTING AN OBJECT BURIED BELOW AN INTERFACE USING TOTALLY REFLECTED WAVES

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OFFICE OF NAVAL RESEARCH
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13. ABSTRACT

A preliminary survey of literature pertaining to the acoustic detection of objects buried at subcritical angles in sediments is presented. Although no general solution to this problem has been found, it is shown that theoretical solutions for similar problems provide a basis for the development of theory for subcritical target detection.

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II

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III

ON THE POSSIBILITY OF DETECTING AN OBJECT BURIED BELOW AN INTERFACE USING TOTALLY REFLECTED WAVES

Description of the Problem

Dr. C. M. McKinney has suggested that even if an acoustic wave in the water is totally reflected from the bottom, the acoustic field still penetrates into the bottom. Thus a scattered wave results whenever a buried object is present, and it may be possible to detect the resulting echo. The illumination of the source may be realized by two different configurations, shown in Fig. 1.

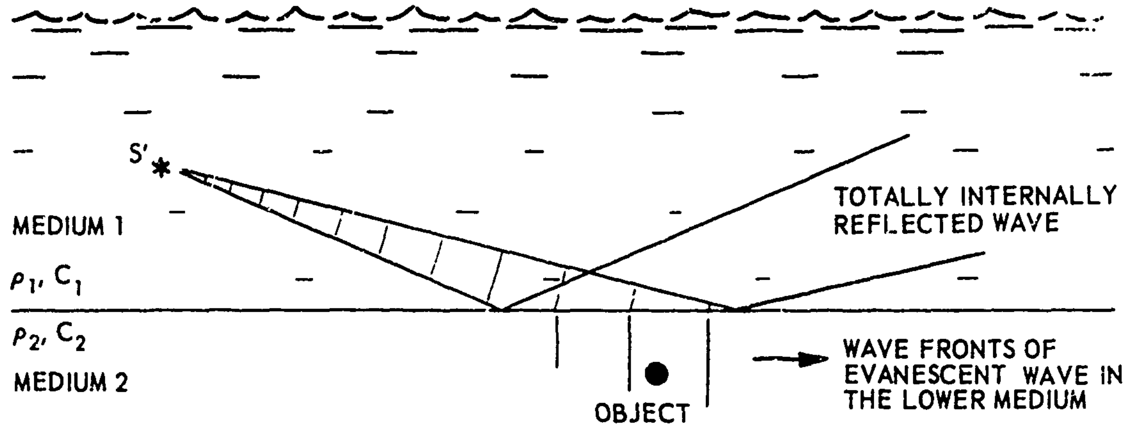
It is not clear at this time if the scattered wave can return by the travel path shown in Fig. 1a. It seems certain, however, that some energy will be returned along the path shown in Fig. 1b.

Suppose we approximate the behavior of the bottom by neglecting the shear modulus and thereby treat it as a fluid. Further, let us suppose that the acoustic velocity in the bottom is greater than that in the overlying water layer so that total internal reflection can occur.

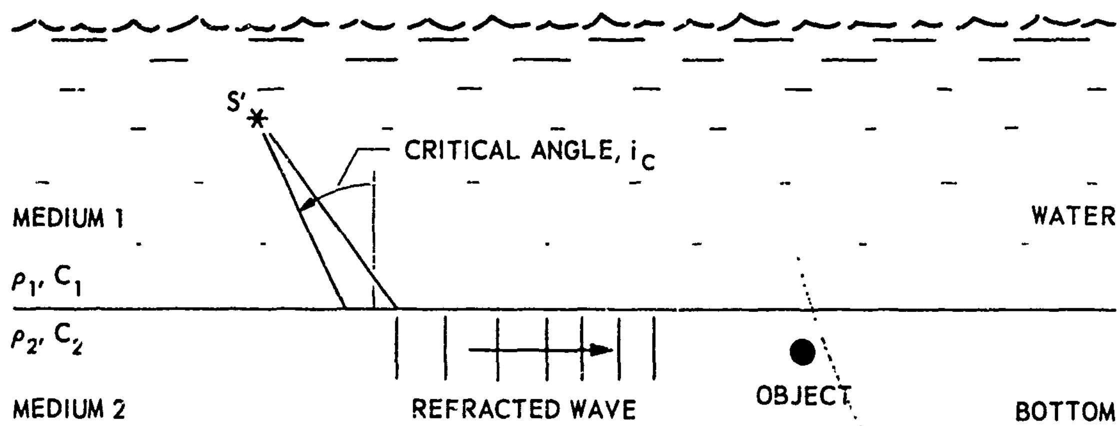
The problem of reflection of a plane wave at such an interface is discussed in many references; a convenient one is Officer[1] who gives the following solution for the geometry of Fig. 2.

Officer (Ref. 1, p. 79, Eq. 2-166) shows that if the velocity potential of the incident wave is given by

$$\phi_{in} \; A \exp\left[i\omega \left\{ t + \left(1/C_1\right) \left(z \cos\theta_1 - y \cos\theta_1\right) \right\} \right] \quad , \qquad (1)$$



(a) USE OF TOTALLY INTERNALLY REFLECTED WAVE
$C_2 > C_1$



(b) USE OF THE REFRACTED WAVE
$i_C = \sin^{-1} C_1/C_2$

FIGURE 1
TWO POSSIBLE CONFIGURATIONS FOR INSONIFYING
AN OBJECT BURIED IN A MARINE SEDIMENT

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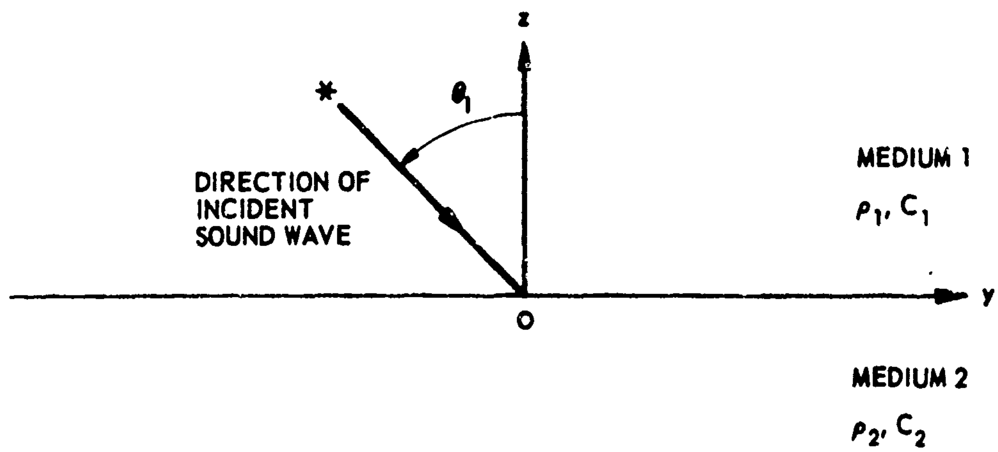

FIGURE 2
THE COORDINATE SYSTEM USED TO DISCUSS
THE REFLECTION OF ACOUSTIC WAVES

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then the resulting velocity potential in medium 2 is

$$\phi_2 = fA \exp\left[a_2 z + i(E/2) + i\omega\left\{t - \left(y/C_1\right)\sin\theta_1\right\}\right] \quad , \qquad (2)$$

where

$$a_2 = k_1\left[\sin^2\theta_1 - \left(C_1/C_2\right)^2\right]^{1/2} \ (>0) \quad ,$$

$$f = 2\left[\left(\rho_2/\rho_1\right)^2 + \frac{\sin^2\theta_1 - \left(C_1/C_2\right)^2}{1 - \sin^2\theta_1}\right]^{-1/2} \quad ,$$

ω = angular frequency ,

$k_1 = \omega/C_1$, and

E = constant given by Officer's Eq. 2-162 .

The important point of this problem is that the wavefield in the lower medium propagates in the direction of positive y, with a phase velocity $C_1/\sin\theta_1$, but that lines of constant amplitude are parallel to the interface and the amplitude decreases exponentially with depth below the surface. However, if $\sin\theta_1 - \left(C_1/C_2\right) \ll 1$, the penetration will be much greater than the wavelength λ_1.

If an obstacle is located in the medium ($z<0$), it will scatter the waves ϕ_2 and, in particular, a wave will be scattered in the direction of the negative y axis which may be detected by the transducer that produced the incident field, ϕ_{in}. It is not possible to predict the magnitude of the scattered wave since the theoretical problem just outlined has not been solved. The purposes of the present note are to outline an approach to the solution and to summarize some of the literature on similar problems.

A Method for Obtaining an Iterative Solution

Consider a spherical object of radius a, whose center is located at (x=0, y=0, z=-h) in Fig. 2, which scatters the wave given by Eq. 2. The total scattered wave ϕ may be thought of as the sum of a series

$$\phi = \phi_o + \phi_1 + \phi_2 + \ldots \quad , \tag{3}$$

where the successive terms are defined following a scheme developed by Thirunkatachar and Visivathan.[2]

(1) ϕ_o is defined as the field scattered by the obstacle when one ignores the presence of the interface at z=0.

(2) $\phi_o + \phi_1$ is the field which satisfies the boundary at z=0 when the effect of the object is ignored.

In short, there are two reflectors, the object and the interface, and a sequence of corrections is made for the effects of one reflector on the field produced by the other.

Thirunkatachar and Visivathan give a detailed solution of a closely related problem and argue that the iterative solution of Eq. 3 converges to the correct answer. Gregory[3] offers the opinion that this method converges only when the radius of the obstacle is less than the wavelength of the wave in medium 2.

The Zero-Order Approximation

The zero-order approximation has been discussed by Ronchi et al.[4] (although they do not identify their solution in this manner) for the case that the scatterer is a circular cylinder with elements parallel to the x axis. Curves showing the directivity pattern of the scattered

wave and graphs showing the total scattered power are given in their report. These curves have interesting features which suggest that the effect of the obstacle will be observable for suitable physical parameters.

The results given by Ronchi et al. are sufficiently promising so that an extension of their work is desirable. The first step would be to carry out a similar analysis for a spherical scatterer. The second step would be to introduce the effect of the interface on the wave scattered by the sphere. This is the term ϕ_1 in the iterative solution.

Related Work

There are a few papers on related problems that should be mentioned. Thirunkatachar and Visivathan[5] have completed a study using a cylindrical scatterer that is similar in approach to their work on the sphere. In each case they consider an elastic half-space so there is no medium 1 as shown in Fig. 2. Thus, the evanescent wave discussed above must be replaced by a Rayleigh surface wave.

Gregory has published two lengthy analyses[3,6] of the problem of a cylindrical cavity imbedded in an elastic half-space. In the first of these papers he develops a suitable set of functions that satisfy the boundary conditions on the free surface as well as the Sommerfeld radiation condition at infinity. In the second paper[3] he uses these functions to solve the problem of the scattering of a Rayleigh wave (and other waves) by the cylinder. Gregory is undoubtedly correct in his claim that his solution is far more general than that of the two Indians, but their solution will be much easier to implement in terms of numerical values.

Conclusions

The problem of the scattering by a buried object of a wave that is totally internally reflected or is refracted at the critical angle has

not been solved in the literature. However, solutions of closely related problems suggest that adequate approximate solutions can be developed and it seems these solutions will indicate favorable scattering strengths.

REFERENCES

1. C. B. Officer, Introduction to the Theory of Sound Transmission (McGraw-Hill Book Co., Inc., New York, 1958).

2. V. R. Thirunkatachar and K. Visivathan, "Dynamic Response of an Elastic Half-space to Time Dependent Surface Tractions over an Embedded Spherical Cavity," Proc. Roy. Soc. Ser. A 287, 549-567 (1965).

3. R. D. Gregory, "The Propagation of Waves in an Elastic Half-space Containing a Cylindrical Cavity," Proc. Camb. Phil. Soc. 67, 689-710 (1970).

4. L. Ronchi, V. Russo, G. Toraldo di Francia, and C. Zaccagnini, "Scattering of Evanescent Waves by Cylindrical Structures," Tech. Note No. 8, Centro di Studio per la Fisica delle Microonde, Florence, Italy (October 1960).

5. V. R. Thirunkatachar and K. Visivathan, "Dynamic Response of an Elastic Half-space with Cylindrical Cavity to Time Dependent Surface Tractions over the Boundary of the Cavity," J. Math. Mech. 14, 541-571 (1965).

6. R. D. Gregory, "An Expansion Theorem Applicable to Problems of Wave Propagation in an Elastic Half-Space Containing a Cavity," Proc. Camb. Phil. Soc. 63, 1341-1367 (1967).

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